



Impact of Soldier Helmet Configuration on Survivability

by Natalie Eberius and Patrick Gillich

ARL-TR-5476

March 2011

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Aberdeen Proving Ground, MD 21005-5068

ARL-TR-5476**March 2011**

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188		
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1. REPORT DATE (DD-MM-YYYY) March 2011		2. REPORT TYPE Final		3. DATES COVERED (From - To) October 2009–November 2009	
4. TITLE AND SUBTITLE Impact of Soldier Helmet Configuration on Survivability		5a. CONTRACT NUMBER			
		5b. GRANT NUMBER			
		5c. PROGRAM ELEMENT NUMBER			
6. AUTHOR(S) Natalie Eberius and Patrick Gillich		5d. PROJECT NUMBER AH80			
		5e. TASK NUMBER			
		5f. WORK UNIT NUMBER			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: RDRL-SLB-W Aberdeen Proving Ground, MD 21005-5068		8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TR-5476			
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)			
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)			
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT <p>The survivability provided by different types of U.S. Army helmets is influenced by the ballistic protection offered and the geometric area of coverage. The fit and wear of each type and size of helmet is a significant factor in survivability grading. The modeling resolution currently available in the Army survivability/lethality/vulnerability models, MUVES-S2 and Operational Requirement-based Casualty Assessment (ORCA), support the ability to assess minor changes seen in helmet configurations and their associated effects on survivability. This report describes how MUVES-S2 with ORCA can be leveraged to model slight wear differences between helmet configurations and their effect on Soldier survivability. The sensitivity of observed fit and wear and current guidelines will be examined. While this type of assessment is not an end-all means for grading helmets, it can provide decision makers and personal protective equipment designers a means for evaluating benefits vs. costs in risk-benefit analysis.</p>					
15. SUBJECT TERMS helmet, ORCA, survivability, injury, incapacitation, body armor					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Natalie Eberius
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (Include area code) 410-278-5219

Contents

List of Figures	iv
List of Tables	v
1. Purpose	1
2. Background	1
3. MUVES-S2 Methodology	2
4. ORCA Methodology	2
5. Modeling and Simulation Process	3
6. Summary	7
Distribution List	8

List of Figures

Figure 1. Measurements of helmet wear on the Soldier.	4
Figure 2. Digital renderings of the PASGT, ACH, and CVC.....	5
Figure 3. Grid plots comparing ACH, CVC, and PASGT.....	5
Figure 4. Grid plots comparing three fits within normal wear guidelines.	6
Figure 5. Grid plots comparing three measured configurations.	6

List of Tables

Table 1. MAIS levels.	3
Table 2. Effect of ACH position on personnel survivability.	7

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1. Purpose

This report describes a modeling and simulation approach and methodology used for assessing the effect that minor changes in helmet wear have on personnel survivability.

2. Background

The ballistic protection of the U.S. Army helmet is optimized when worn according to the fit and wear specifications provided with the helmet.¹ The Soldier must first ensure proper fit followed by proper wear. The combination of proper fit and wear will optimize the ballistic protection of the helmet. Proper helmet size is determined through three head measurements. The first measurement is head length, which can be described as the maximum length of the head measured from the back of the head to the forehead. This measurement can also be described as the distance from the occiput to the glabella. The second measurement is head width, which can be described as the maximum horizontal width of the head measured above and behind the ears. The third measurement is head circumference, which is measured just above the bony brow ridges of the forehead and above both ears.

The proper wear of the helmet is most easily obtained when the helmet has been properly fit. One element of proper helmet fit is the lift, or height, where the helmet sits on the head. The lift is deemed too high when crown pads are not touching the head or there is too much exposure of the forehead. Additionally, the helmet cannot sit too low, which is evident when the helmet covers the eyebrows and the helmet interferes with eyewear. The helmet should remain in place when the head is shaken. The helmet should fit so that the front rim is no more than 0.5 in above the eyebrows. Helmet height (advanced combat helmet [ACH] only) can be quickly assessed by looking at the height of the helmet relative to the ear canal openings. The bottom of the helmet should come to the top of the ear canal opening. This report will focus on the ACH; however, the CVC and personnel armor system for ground troops (PASGT) are also analyzed.

Feedback from Operation Iraqi Freedom/Operation Enduring Freedom indicates Soldiers may not be properly wearing the ACH. The U.S. Army disseminated a maintenance advisory message (MAM) which states, “This message is provided to remind commanders of the correct fit and wear standards of the helmet and to provide instructions for corrective actions on improperly worn helmets. The ACH provides the user greater situational awareness, comfort and fit than the standard PASGT (Kevlar) helmet. It is also compatible with the interceptor

¹ U.S. Army Soldier and Biological Chemical Command. *This is Your Ballistic Helmet*; Natick Pamphlet 70-2; Natick, MA, July 2000.

body armor (IBA), offering the Soldier improved target acquisition in all rifle and carbine firing positions, especially the prone position. However, in cases where the ACH is improperly fitted and worn too high on the head, the Soldier may be exposed to increased risk from fragmentation. Improper wear may be caused by misunderstanding the wear standards, poor pad placement inside the helmet, improper fit, the incorrect crown pad inside the helmet, or a combination of the above.”²

The visual differences in correct wear compared to incorrect wear may be slight and difficult to ascertain. These differences can pose a significant effect on Soldier survivability. These small wear differences will be analyzed using MUVES-S2 with embedded Operational Requirement-based Casualty Assessment (ORCA).

3. MUVES-S2 Methodology

The MUVES-S2 model is a stochastic, component-level survivability/lethality/vulnerability (SLV) software suite that simulates the effects of indirect- and direct-fire munitions against modeled targets. MUVES-S2 with embedded ORCA provides the standard computer simulation platform for evaluating effectiveness of munitions and missiles and the survivability and vulnerability of personnel, aircraft, missiles, and ground systems. MUVES-S2 has a long history of use and acceptance in the evaluation of vehicle and personnel vulnerability. Both MUVES-S2 and ORCA have been used during all phases of system acquisition from research, design, and development to production, test, and evaluation and have been verified, validated, and accredited for major programs in acquisition. The MUVES-S2 capabilities are fully integrated into the test and evaluation process from concept design to production milestone decisions for SLV evaluations.

4. ORCA Methodology

ORCA determines the type, severity, and frequency of injuries sustained by personnel as well as the percent reduction in human capability from impacting munition fragments. Some of the features provided by ORCA when compared to earlier methodologies include a more precise anatomical representation, the ability to map injuries to physical and cognitive impairment, evaluation of basic human capability requirements to postinjury capabilities, and an accommodating methodology for improvements.

² U.S. Army MAM, Control No. 04-001-013. Correct Wear Standards and Fitting Procedures for the ACH. <http://peosoldier.army.mil/soldierscorner/ach.asp> (accessed October 2008).

ORCA development has been ongoing since 1998 by the U.S. Army Research Laboratory (ARL). The U.S. Army, Navy, and Air Force, other government agencies, academia, and private industry have also aided in model development. ORCA is a high-resolution computerized personnel casualty model that can be used to assess the impact of various casualty-causing insults on personnel. ORCA classifies each computed penetrating injury using the Abbreviated Injury Scale – 1985 Revision (AIS-85), which is a standard measure of individual anatomical injury. AIS is an anatomically-based, consensus-derived, international severity scoring system that classifies each injury by body region according to its relative importance on a six-point ordinal scale. Examples of maximum abbreviated injury scale (MAIS) levels are outlined in table 1.

Table 1. MAIS levels.¹

MAIS	Injury Level	Type of Injury
0	No injury	None
1	Minor	Superficial
2	Moderate	Reversible injuries; medical attention required
3	Serious	Reversible injuries; hospitalization required
4	Severe	Reversible injuries; not fully recoverable without care
5	Critical	Nonreversible injuries; not fully recoverable, even with care
6	Maximal	Nearly unsurvivable

5. Modeling and Simulation Process

The process of evaluating changes in helmet wear and the effect of Soldier survivability are described as follows:

1. Helmet placement was determined by ARL's Human Research and Engineering Directorate (HRED) through Soldier helmet wear.
2. Helmet geometries were digitally scanned in three dimensions, converted to BRL-CAD format, and positioned on the digitized anatomical head represented in the ORCA model.
3. The MUVES-S2/ORCA model was used to compare the ballistic protection provided by the helmets for a bullet threat where the measure of effectiveness was the probability of receiving a serious or greater injury.

The ACH helmet was the main focus of this study; however, the CVC and the PASGT were also assessed to a lesser degree. The correct ACH wear positions is denoted as position X, and two tilts from X are denoted as X₁ and X₂ (3° and -3°, respectively). Additionally, two measured alterations of position X are denoted as positions Y and Z. The CVC and PASGT helmets wear were not measured from Soldier wear and were assessed analytically only. The CVC was

assessed parametrically with 4-, 6- and 8-mm lifts. The PASGT was assessed in the correct wear position only. The ACH helmet coverage measurements were performed by ARL/HRED. A depiction of the measurement process of helmet wear on a Soldier's head is shown in figure 1. An overview of the targets and wear conditions assessed is outlined as follows:

1. No helmet
2. ACH (note: tilt is forward when angle is > 0)
 - Configuration X: 0-mm lift, tilt 0° (correct wear position)
 - Configuration X1: 0-mm lift, tilt 3°
 - Configuration X2: 0-mm lift, tilt -3°
 - Configuration Y: 4-mm lift, tilt 0°
 - Configuration Z: 7-mm lift, tilt -7°
3. CVC
 - Correct wear position and lift of 4, 6, and 8 mm
4. PASGT
 - Correct wear position

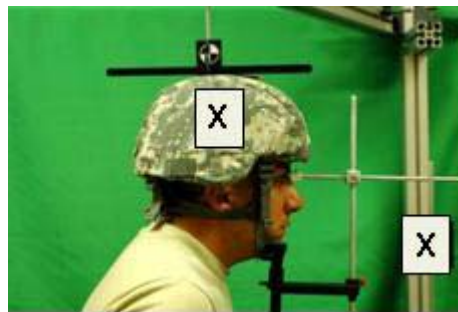


Figure 1. Measurements of helmet wear on the Soldier.

The ACH and CVC helmets were digitally scanned and placed on the digitized ORCA man's head. Renderings of the digital scans are shown in figure 2. The ballistic protection of the helmet was not a variable in this study; the threat was modeled as never penetrating the helmet. The vulnerability of the head with the various helmet configurations was assessed at 5° azimuthal increments around the head. Each of these azimuths was assessed for elevation 0° . Injury plots at each of these azimuths were modeled on a uniform grid of 1×1 -mm shot lines. Each shot line is then assessed by the ORCA model, and the MAIS value is assigned to each 1×1 -mm grid cell. The results of the injury analysis of the head with ACH, CVC, and PASGT

helmets (correctly worn) are depicted in figure 3. The helmet with the most coverage is the PASGT and therefore receives the lowest probability of a serious or greater injury. However, as stated earlier, the ACH provides enhanced situational awareness, field of vision, hearing, comfort, and fit over the PASGT helmet. The ACH is also compatible with the IBA, which offers improved target acquisition in all rifle and carbine firing positions, especially the prone position.

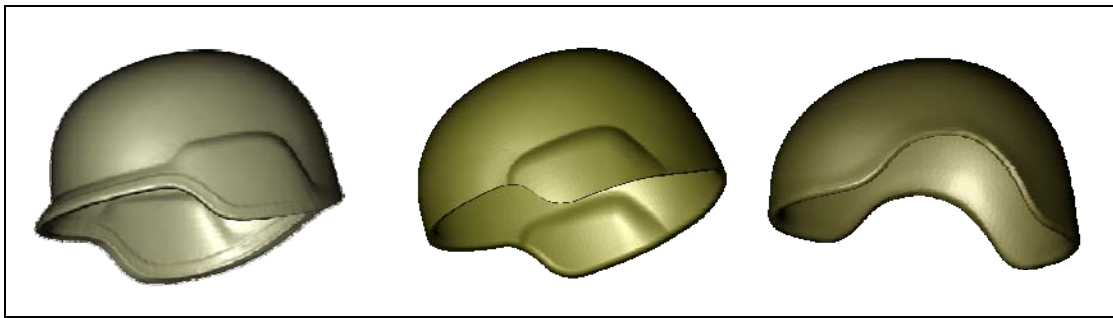


Figure 2. Digital renderings of the PASGT, ACH, and CVC.

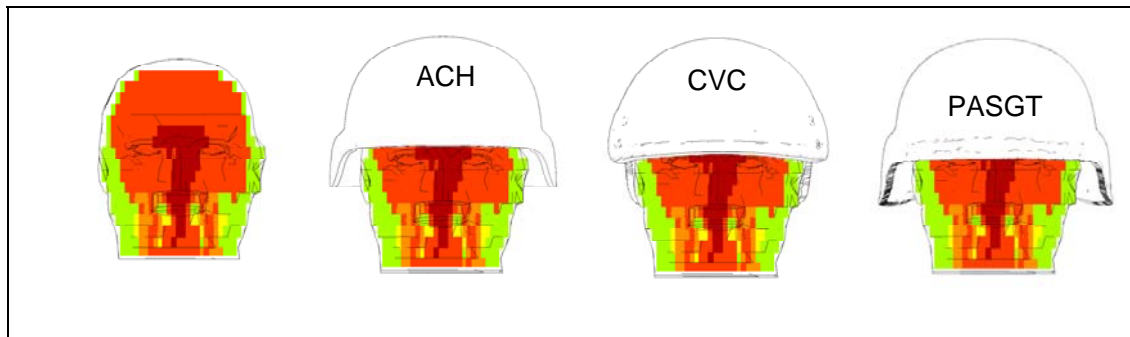


Figure 3. Grid plots comparing ACH, CVC, and PASGT.

The results of the injury analysis of the head with the ACH in the modeled configurations are depicted in figures 4 and 5. The configuration with a 3° forward tilt presented a small improvement in overall survivability. The configurations with nonstandard lifts (Y and Z) always resulted in a lower overall survivability, even though some aspect angles covered more of the head.

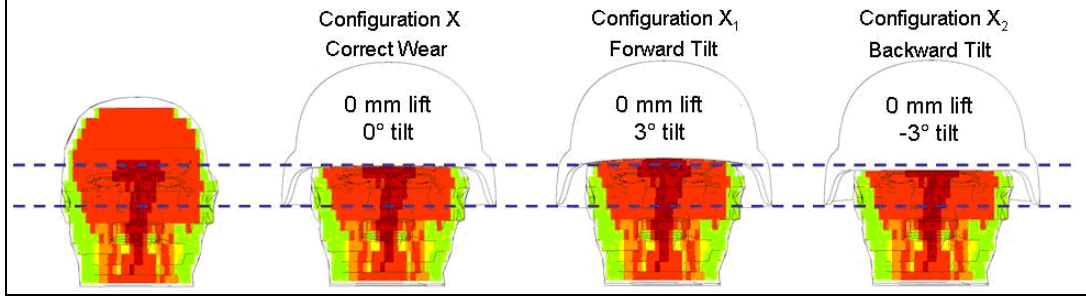


Figure 4. Grid plots comparing three fits within normal wear guidelines.

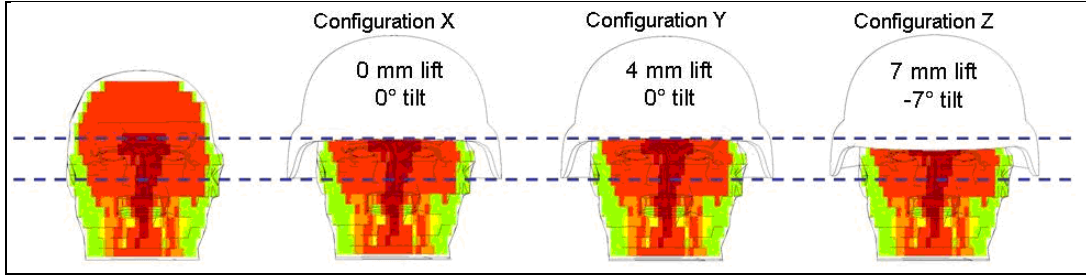


Figure 5. Grid plots comparing three measured configurations.

The calculated survivability data was also compiled to focus on various aspects described as the frontal arc, side arc, and rear arc of the head. Configuration X_1 provided the lowest probability of serious injury overall as well as from the side and rear. The lowest probability of injury from the frontal arc was provided by configuration Z (7-mm lift and -7° tilt). However, as expected, this configuration failed at all other aspects.

Pair-wise comparisons were used to determine whether measured differences were statistically significant at each azimuth and elevation grid view between the standard helmet position and each tested configuration (shown in table 2). A Wilcoxon Signed Ranks Test was applied with the following one-tailed hypotheses:

$$H_0: E(X) \geq E(Y), \text{ and } H_1: E(X) < E(Y), \quad (1)$$

where $E(X)$ is the probability of a serious-to-maximal injury in the helmet configuration and $E(Y)$ is the same measure in the standard helmet configuration. When comparing the results, the null hypothesis was rejected in every case with an α exceeding 0.0001 as the T values were always less than -3.7190 . In the case which configuration Z was compared directly to configuration Y, the ACH with configuration Z showed a higher probability of injury vs. the ACH with configuration Y with a T value of -8.06 .

Table 2. Effect of ACH position on personnel survivability.

Statistical Comparison	T Value
Correctly worn ACH vs. ACH with configuration Y	-16.44
Correctly worn ACH vs. ACH with configuration Z	-12.43
Correctly worn CVC vs. CVC with 4-mm lift	-16.44
ACH with configuration Y vs. ACH with configuration Z	-8.06

6. Summary

Using the MUVES-S2 with the embedded ORCA can be a resourceful tool in ascertaining the effect of small or slight helmet wear changes on survivability. The variable of ballistic protection can be simulated, as well as other helmet add-ons that effect survivability. The methodology outlined in this report can be used for all current and future body armor survivability studies.

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